The design and implementation of experimental collaborative learning in a Distance Learning context

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Abstract – **This paper deals with the design of collaborative support for experimental learning, focusing on the articulation of actions in a laboratory, either real or virtual, and argumentation. The approach presented here takes place in a distance-learning context where three phases can be distinguished: pre-lab, lab and post-lab. The goal of the pre-lab phase is to provide students with motivation and context for the lab phase, in order to situate theory and experimentation. Students and teachers work within a computer supported environment used to carry out a combination of individual and collaborative processes. The technological infrastructure permits the integration of tools and devices together with the reuse of the results generated by students in their learning activities. An illustrative example from the domain of organic chemistry is presented.**

I. INTRODUCTION

A growing number of studies have been undertaken regarding the design of computer support for learning collaboratively scientific reasoning. Activities have been widely used that involve microworlds or simulations in which experiments are undertaken and data are collected. Furthermore, discussion is highlighted as a primary medium for knowledge building in science. A variety of techniques have been proposed to promote and reify scientific dialogue in learning situations: (i) representational tools for modelling and argumentation can be used synchronously either by face to face interaction or via distributed access [5, 7, 12, 15]; (ii) semi-structured hypermedia databases allow students in different locations to create notes, choose and assign labels to them as well as establish connections with other authors' notes in order to build a learning community database by incremental, asynchronous and distributed processes [3, 6, 11] (iii) conversational tools to scaffold students interactions [1, 2, 10] .

Some interactive and collaborative tools have become technically affordable for a wide spectrum of the educational community, opening up the possibility to support socially constructivist learning approaches in computer-based environments, which can be deployed in a distance learning framework. This paper deals with the design of collaborative support for learning science, treating learning as a process of knowledge construction. The setting for this work is a distance learning university. The aim is to support learners in complex learning tasks, involving laboratory experimentation. The learning environment has to provide articulation and integration between the experimentation space and the argumentation space, with facilities for handling different types of information (text, video, graphics) generated by a variety of tools such as: drawing tools, databases, simulators, different domain specialized editors, personal and shared notepads, modelling tools and communication tools. For this purpose we have created a computational model [14], grounded in the Activity Theory, where the system architecture includes a structured learning object repository, which permits the specification, storage, and flexible search, combining a variety of tools and resources for a learning community.

The paper is organized as follows: section 2 presents the motivation for our proposal and briefly describes the reshaping of the current experimental context; section 3 outlines the repository, a structured and dynamic container with functionality that supports tasks involving a variety of resources and devices, so that students could produce, share and reuse the outcomes of their experimental learning activities. In section 4 an example scenario is presented to illustrate the use of the system. Finally, some issues for future work are presented.

II. MOTIVATION

In distance education institutions, such as the UNED[1], the study of experimental subjects requiring lab work, is organized in turns, where students come to the University to participate in an intensive lab stage lasting between three to six days, in the middle or at the end of the academic year. They receive a handout with guidelines on how to perform the experiments before coming to the lab, and they have to write a report at home following it. The lab is an interesting experience for students even if not well integrated with their individual study throughout the academic year.

Networked technologies open the way to the creation of new lab frameworks for science education in a distance-learning context. While physical presence and manipulation still remain crucial, this lab work can be better integrated with the rest of the learning period. There are many possibilities for new design, some of which have been mentioned in the introduction. The approach adopted here started from the current situation, looking for opportunities to improve the process, given a very realistic and learner-centred perspective. Subsequently, a pilot lab course in organic chemistry was created, using a scalable model that takes into account the constraints of the social context in which this work is taking place.

[1] UNED is the Spanish Open University, operating worldwide with about 200.000 students

First of all the current practice was analysed, taking into account the observation of a series of student lab sessions throughout the academic year 2000, together with subsequent in-depth discussion with the teaching staff. As a result, a couple of major problems were identified:

- Students are provided with documentation about the lab work in advance but they do not work with or even look at the guidelines before coming to the sessions. The tight schedule of the lab sessions does not favour thinking and reflection. This, together with the fact that they have no previous experience, means that students in the lab need to focus on figuring out what to do, making interpretations as they go about the procedures outlined in the guidelines; similar to following a recipe. The result is a very poor articulation between the theoretical knowledge students have and the practical manipulations they are carrying out.

- Experiments are performed in groups of two. They have no previous experience either of collaboration or collaborative support for the work they have to perform together in the lab. For instance, each student uses personal notepads to write observations and a copy of the guidelines to make annotations during the lab period. Often they do not check whether their notes are complete, complementary or inconsistent. These sketchy notes are used afterwards but usually the final report is a document written from scratch.

To cope with these problems, and taking into account that lab schedules could not be changed for organizational reasons at institutional level, the inclusion of a pre-lab period was proposed where students, at home, at their own pace, could carry out virtual lab activities in collaboration.

The new framework

Three phases are considered necessary for this process, as can be seen in figure 1. For each phase, a computer-supported environment offers a structured scenario with functionality for carrying out individual and collaborative activities. A variety of mediational tools are available, some for the whole period such as structured glossaries, others specifically intended for a particular phase, such as simulation models. During the PRELAB students working at home carry out problem solving tasks to develop an understanding of the subject matter. In the LAB, students work in a real laboratory and focus on the manipulation of chemical tools and chemical processes; the system supports data collecting as well as some collaborative modelling in this phase; and in the POSTLAB, students use the system from home in a collaborative fashion to reflect upon and discuss in depth the theoretical background and the experimental work carried about in the lab.

A. Pre-lab

The goal here is to provide motivation and context for the lab phase, in order for the students to integrate theory and experimentation. An environment is provided where individual and remote collaborative activities are combined. Activities are structured in order to focus student attention on the issues they should learn: content-related and problem-solving techniques as well as interpersonal skills.

The environment enables students to undertake a "simulated" lab experience. An experiment is presented as a space of related tasks where, the computer definition includes all the possible steps or paths that could take place during experimentation. Students have to collaboratively explore the task space and decide which subtask has to be performed next for a particular problem-solving situation. Students can request *direct observations* (for instance the colour of a composite) and *results* (for example the boiling point when the composite is heated), provided by simulation techniques. The environment is seen by students as a personal structured notepad, where the performed tasks are recorded as well as the outcome obtained from the use of different tools. This information can be consulted or reused in further tasks.

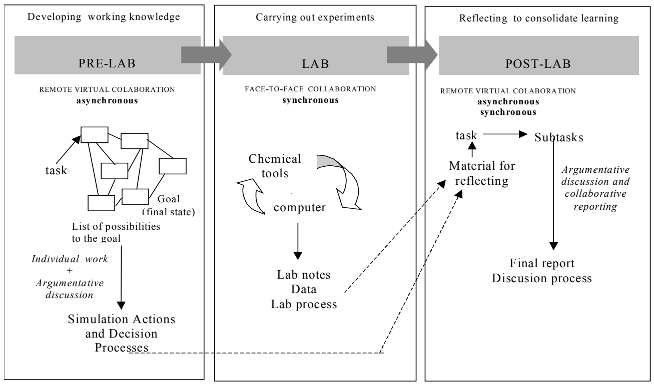

Figure 1. The three phases

B. Lab

Students carry out experiments in the lab in pairs. A computer is available in each lab workplace. The support environment is similar to the pre-lab, but the contents and functionality are enriched, for instance help about how to do a particular manipulation is provided on demand (this kind of advice can take the form of animations). Furthermore, input data from a variety of devices is stored. Collaboration is important here, and our expectation, confirmed by later experiences, was that collaborative practice in the previous phase established patterns for this second situation where students meet for the first time and work together for three days in the same place. Hypothesis formation in the pre-lab phase does help students to handle the experimental space. Students input the data with PDA (Personal digital assistant) devices because they are more suitable for a Chemist lab (small and handy) than a desktop computer. The environment offers import/export facilities from their notepads for a variety of tools. A repository provides persistence and reusability. Data is also collected from other devices, and can take a variety of formats, for example photos taken by the students of the processes and intermediate results. Students are encouraged to annotate, comment and discuss data together.

C. Post-lab

Students work together from home via remote collaboration to prepare their final reports. Two configurations are supported, using either asynchronous or synchronous tools. The tools include functionality that provides access to the learning repository. The reports should include not only the data previously obtained, but also elaborated explanations. I.e., students progress from a **general description** of what happened, to a **causal explanation** (why did it happen?), and to a **justification** of the causal explanation (what the evidence supports?). Some questions proposed by teachers during the lab help them in this task.

Assistants are also actors in the learning community; the system supports their task in the post-lab phase. Each assistant has to mark, comment upon and assess a group of students. There is a tool to read and annotate the reports as soon as students decide to submit them. Students automatically receive a notification once this feedback is available.

III. A LEARNING OBJECT REPOSITORY FOR COLLABORATIVE AND EXPERIMENTAL LEARNING

In order to store partial results between each stage, a structured container is required. The partial results (learning objects) should be stored in such a way as to provide a set of common services, which can be undertaken with them. Facilities are needed for searching, downloading, saving, annotating, indicating relationships between objects, inclusion of events associated with objects, storage of different "versions of the same object", and the provision of some degree of interoperability.

A Learning Object Repository (henceforth, LOR) has been developed (see figure 2). The repository is a storage structure that mediates between the student and the resources with which s/he can work. This organisational structure permits an exploration of the way in which the tools can be used to favour collaboration and communication in order to undertake the given tasks. It stores the data encapsulated as learning objects. Current standardization efforts are taken into account, so that learning objects are stored in a container together with standard metadata [4]. For metadata elements, the recommended vocabularies (in most cases just a list of identifiers) are used. Other concepts, related to learning tasks and collaboration, not taken into account in current educational metadata, are also included. These concepts are represented in a number of ontologies, which provide a vocabulary to describe entities, classes, properties, predicates, functions, and a set of relationships between vocabulary elements. The container stores a catalogue of the learning objects currently defined.

A wide set of well chosen metadata would ensure the right granularity for the knowledge description and usage. However, a large vocabulary with rich metadata would not suffice, because it would lack the structure to provide both meaningful relationships and abstraction levels. A plain vocabulary with fine-grained metadata would allow any object in the container to be retrieved by pattern matching. A taxonomically organised network, i.e., an ontology, allows the use of semantically enhanced search engines (an enrichment, in the sense of [9]). Furthermore, this approach dynamically generates the LOR functionality adapted to the needs of particular learning communities.

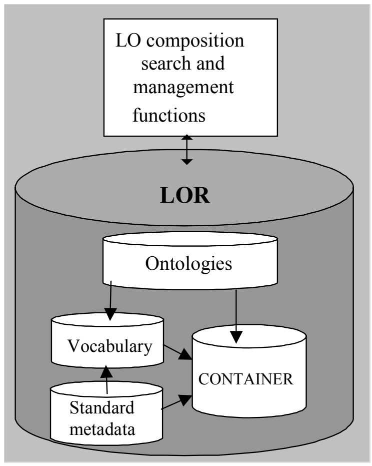

Figure 2. Learning Object Repository Structure

IV. SCENARIO DESCRIPTION

An example of the application of this platform for second year laboratory sessions in a degree course in Organic Chemistry in the UNED's Engineering School is shown in figure 3.

During the **pre-lab phase** students have been working at home, using the virtual environment. This environment offers an integrated space of resources where students have to solve a set of problems. The environment includes general domain knowledge, such as a glossary, and specific content for each kind of problem to be solved, for example:

- The objective of the virtual experiment
- A minimal theoretical background
- A description of the experiment in terms of a set of tasks.

The environment is generated from a specification template, also a learning object; see [14] for further details about the whole architecture. Different collaborative strategies could have been implemented. For the first pilot study, based on previous experiences in the context of distance learning [13], the following has been deployed:

Students start by solving a simple problem individually, in order to became familiar with the environment, and then work in pairs for a more complicated one. Typically an experiment is made up of a set of related essays together with some modelling or interpretation of the collected data. For the essays, students are asked (1) to explicitly discuss and negotiate some critical decisions: for example which tests and in which order should be undertaken, and (2) to identify hypothesis, data and conclusions for each essay they decide to carry out and (3) to comment on the results obtained.

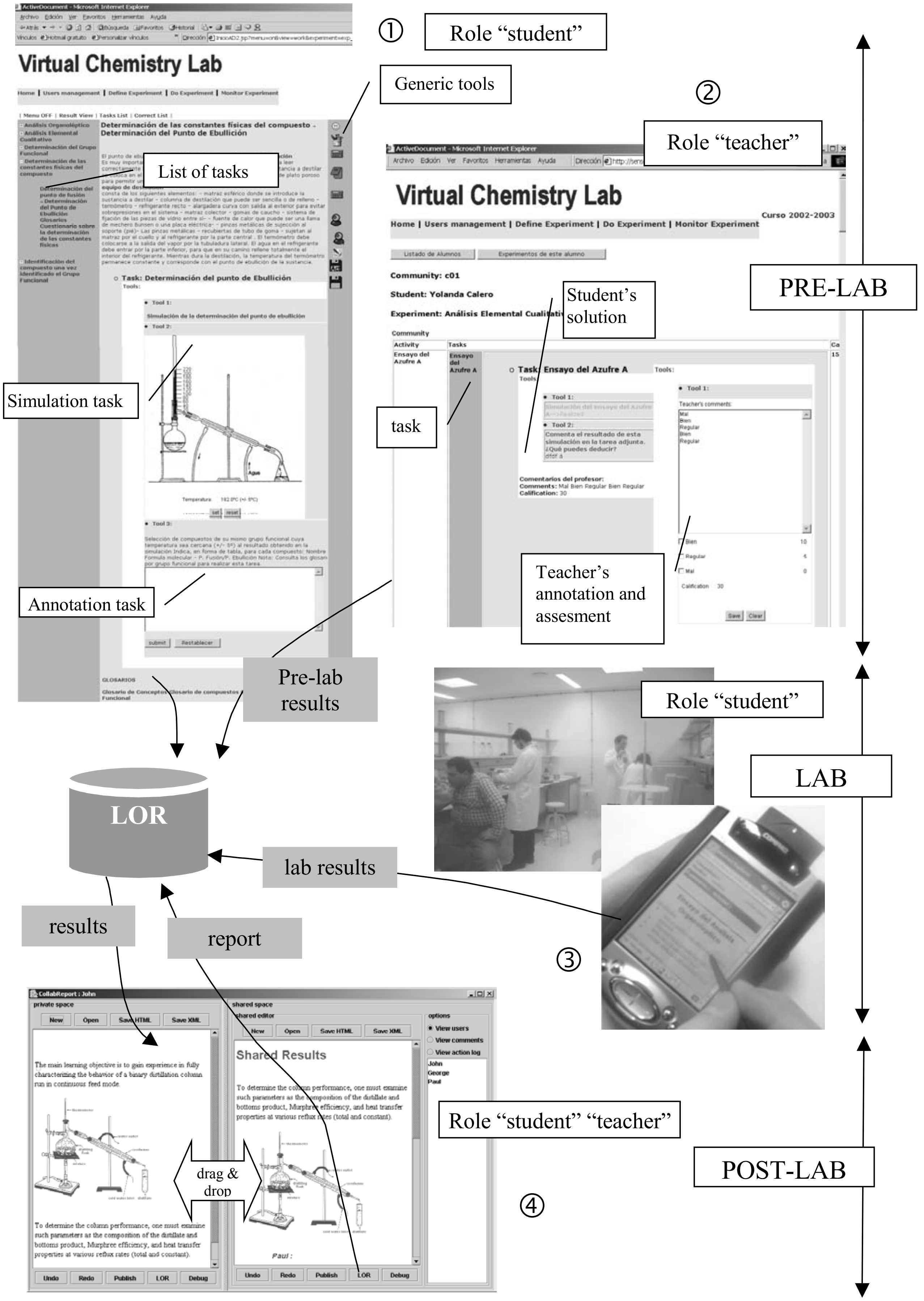

Figure 3. Scenario description

An experiment usually involves several tasks. Thus an experimental description is divided into several subtasks and for each one there are some indications about the particular constraints as well as the different possible methods available to perform them. In more abstract terms, the problem can be said to be represented as a search in a task space. Not all the tasks need to be done for a particular case. Each pair of students need to solve a different case, selecting the subtasks and the steps to be performed for a particular problem. The student environment for a particular task contains links:

- To a multimedia glossary as well to other sources of information.
- To workspaces, either personal or shared.
- To a set of domain tools such as specialized editors, simulators o databases
- To a semi-structured conversational tool

The glossary contains domain knowledge: concepts, properties, instruments, procedures…. defined or explained in different structured ways. The rationale here is to promote an active, **goal-oriented** approach for providing information. As has been previously noted: "*people learn best when engrossed in the topic, they are motivated to seek out new knowledge because they need them in order to solve the problem at hand*" [8] .

The set of workspaces in the environment can be viewed as being a personal notepad, structured and related to the subtasks each student has selected to carry out for a particular problem. The environment supports multimedia objects with different representations. For instance, an appropriate word processor for chemistry is available to build formulae as graphics and the results are copied into the notepad. Furthermore, the results of a search in an infrared spectrum database can also be stored. All the tools are integrated into the environment, so that students can easily use them and copy the outcome in their notepad. The LOR is the underlying infrastructure for this persistent storage.

To solve a problem, students have to adopt a search strategy in the task space. For each candidate task students have to

i. Discuss and take a decision regarding whether to do it or not, justifying their choice
ii. In the case of performing a task, i.e. when carrying out a test to collect evidence, they have to explicitly identify their initial **hypothesis**, the collected data and the **conclusions** reached. In this pre-lab phase students obtain the data either by running a simulation, or by querying a multimedia database.

Some **advice** is available about particular choices. This advice is configurable, using two parameters, one fixed by the teacher to specify whether or not it should be available for a particular group of students, and another based upon the previous student behaviour, to offer different levels of help. For this purpose, the system builds a simple student model recording student actions.

In figure 3 (labelled as ①) a snapshot of the student interface is presented. On the left menu, a list of possible tasks is presented. When the user clicks on a task name, a workspace for this task with a set of available tools appears on the right pane; in the example two of them are shown: a simulation tool and an annotation tool. Besides, some tools are also available for any task. These tools (shown in the right vertical bar) can be either specific to a domain as, for example, a chemical formula processor, or general, as a chatting tool or a camera for taking pictures. The results of each task can be stored in the LOR, appropriately labelled with context and author information.

The role of the teacher is firstly, preparatory: to build a set of cases to be used in the pre-lab phase, as well as to organize the groups. Secondly, in the pre–lab phase, it includes monitoring the work of students, based upon some input and support from the automatic tracking performed by the system. Furthermore, students have the possibility of asking the teacher questions related to a particular subtask. These questions and the answers (a kind of FAQ) are dynamically linked to the glossary.

In figure 3, labelled as ② a partial view of the teacher interface is shown. In this case, the tool for correcting the student's work is open. The task description and the students' solution are displayed in the middle. In the column at the far right, the area to annotate and assess the student's solutions is visible. The teacher's annotations are also stored in the LOR. It is up to the teacher to indicate to the system that the student should be allowed to continue or to suggest that a task should be repeated, depending on the assessment.

The environment described here is generic in the sense that it provides a representation for learning activities in terms of a structured problem-solving space of tasks. Learning is viewed as a collaborative exploration mediated by argumentative discussion.

Apart from obtaining data/evidence, students also have to perform other kinds of generic tasks such as modelling, for example in the case of functional analysis of an organic substance they have to collaboratively annotate the relevant peaks of the infrared spectrum with the components they have previously guessed. This is a different situation requiring another kind of collaborative support. For this type of modelling task a collaborative tool combining discussion and direct manipulation on the spectrum is best suited.

During this phase, the role of the LOR is as an intermediate container of data, considering the partial results as leaning objects (automatically labelled with contextual metadata). These students' constructions can be consulted or reused in the next stages.

In the **lab phase**, the students work together in small groups using an interactive on-line environment built with the system: The lab activity consists of the analysis of a chemical compound in order to identify its main components. Adequate experimental procedures and tools have to be selected, reflection has to be undertaken on the results obtained, and finally, a conclusion based upon the evidence obtained has to be elaborated. Due to the nature of a chemistry laboratory, where the presence of standard desktop PCs among the chemicals is somewhat impractical, the student's use PDAs running specially developed client software, connected to the platform via a real time synchronous wireless link (see figure 3, label ③). The environment accepts a variety of inputs, for instance, photos taken by the students, and offers different types of functionality, such the annotation of the results obtained in the lab.

Once the experiment has finished, and the students leave the laboratory, the **post-lab** phase begins: a reporting activity, undertaken at a distance, using any desktop PC, using a standard Web browser to connect to the platform. The results generated during the laboratory can be integrated into a final document which is submitted to the teacher for correction on-line.

The pedagogical goal of the collaborative reporting task is to promote students reflection on results of the past stages. The interface of the collaborative reporting tool is shown in figure 3 (label ④). The left hand part is an individual work area that contains learning objects (extracted from the LOR) and personal comments about them. The right hand side is the common group work area, which has sections that help to structure the reporting task. Students work together to create a final report, where they can integrate the available objects selected from the LOR on the left hand side, to their report (on the right side).

V. CONCLUSIONS

The design of a collaborative scenario for learning experimental science at a distance has been presented. Requirements where established after an in-depth analysis of the current practice. A new pedagogical approach to fulfill these requirements was defined and the software to support the teaching/learning process was incrementally developed following a participatory design approach. The main aspects of the collaborative modeling environment have been outlined and a case study showing the feasibility of deploying this new scenario has been presented. From the learning point of view, students are centered in the construction of knowledge, through a set of tasks mediated by a variety of tools. A repository is the core of the technical infrastructure allowing both tool integration and an incremental production and reuse of student outcomes. In addition to wider experimentation, including the modeling of experiments in other domains, to enrich the resources on the learning repository, on-going technical research is focusing on the design of a layer for the scenario modeler, with an user-friendly interface to dynamically specify (create or modify) new learning activities at run-time, as desired by either the teacher or the students.

VI. ACKNOWLEDGEMENTS

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